CALIFORNIA SPACE GRANT CONSORTIUM

National Aeronautics and Space Administration

NASA

# *NASA Artemis Student Challenge Opportunities*

LEAPFROG

# ***Software Challenge Informational Session #1 for Competition Teams***


***Student Team***

UC San Diego

USC University of Southern California

Berkeley UNIVERSITY OF CALIFORNIA

***Faculty Team***

***John Kosmatka (PI)***
University of California, San Diego

***David Barnhart (Co-PI)***
University of Southern California

***Dan Zevin***
University of California Berkeley


April 7th, 2021

CALIFORNIA SPACE GRANT CONSORTIUM

National Aeronautics and Space Administration

# LEAPFROG is 1 of 3 Theme-3 2020 Awards

## THEME 3 AWARDS – PILOT ARTEMIS STUDENT CHALLENGES

- Lunar/Martian Lander skills competition using existing technology to execute the competition in Earth's gravity and atmosphere
- Develops Artemis-relevant systems engineering and integration skills, and requires innovations to perform well against the other teams
- Requires the development and evolution of critical thinking and hands-on skill sets to enable humankind's next great steps off of Earth

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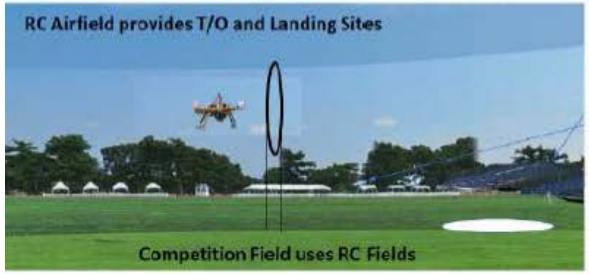
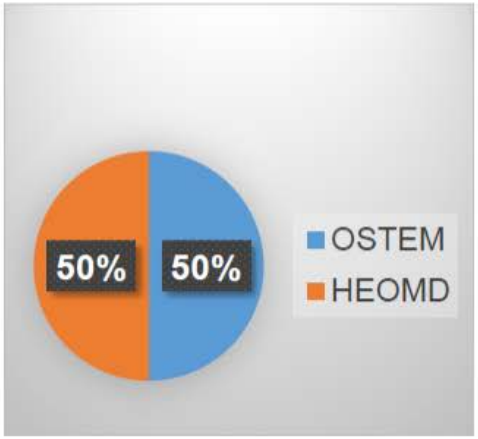
Possible Competition Metrics:
- Flight Time
- Stability and Hold
- Navigation Precision
- Fuel Useage
- Multi-Hop Translation
- Various Guidance Challenges
- Etc




RC Field supports Audience Member Viewing Stands for public involvement




# Artemis LEAPFROG Project Goals

- Update existing USC LEAPFROG lander prototype
- Develop competitions around the Lunar Lander prototype
- Run Competitions in Summer of 2021!

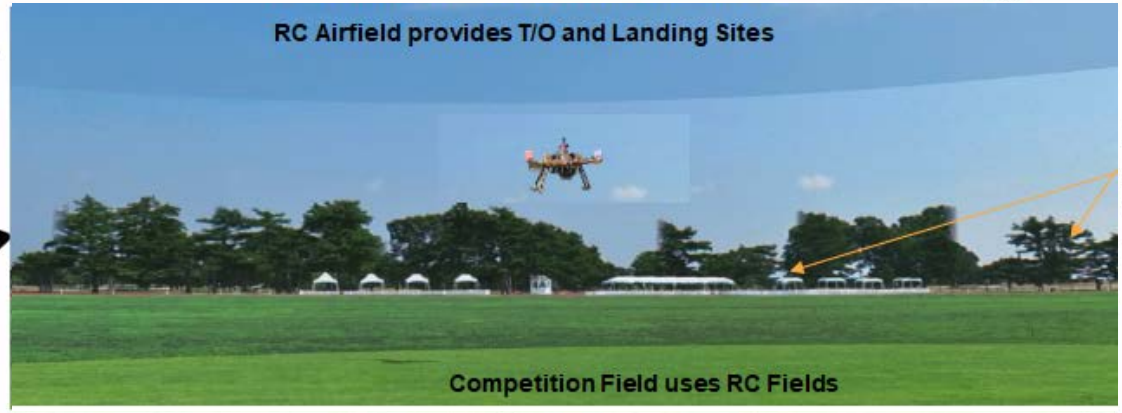
**LEAPFROG Operations Center:**
**Up to 500 meter range**

*Wireless signal booster*

*Laptop Control*

**Possible Competition Metrics:**

- Flight Time
- Stability and Hold
- Navigation Precision
- Fuel Useage
- Multi-Hop Translation
- Various Guidance Challenges
- Etc




**RC Field supports Audience Member Viewing Stands for public involvement**

**RC Airplane Pits: LEAPFROG Fueling and Pre-Flight C/O**

**LEAPFROG Sets up PostFlight Assessment and Scoring**

***Run a national competition in 2021!***

# Timeline

| Activities | Start Date | End Date |
|---|---|---|
| Announce S/W Competition | 3/4/21 | 3/5/21 |
| Run Signups for all potential Teams | 3/5/21 | 4/15/21 |
| Run PX4 and Simulation Webinars | 3/28/21 | 5/12/21 |
| Finalize Teams and Notify | 4/15/21 | 4/22/21 |
| **Seminar #1** | **S/W Tools** | **4/7/2021** |
| **Seminar #2** | **Running the Sim** | **4/30/2021** |
| **Seminar #3** | **Competition Metrics** | **5/12/2021** |
| **Run Software Challenge (4 Weeks)** | **5/15/21** | **6/15/21** |
| Finalize and Contact Winners | 6/16/21 | 6/30/21 |
| Ship out LEAPFROG Vehicle Kits | 7/1/21 | 7/15/21 |
| **Run Vehicle Building Bootcamps & Run Exhibition Flights** | **7/28/21** | **8/11/21** |
| Submit Final Report to NASA | 8/5/21 | 8/31/21 |

# Software Competition Challenge and Exhibition Flights

*~ March to June 2021*

*~ June to August 2021*

## Virtual Software Challenge

### *Crater Landing*

**Goal**: Locate & land in center of designated crater

### *Obstacle Avoidance*

**Goal: I**dentify & maneuver past potential hazards

- Virtual S/W Challenge run remotely
- Skills enable transfer between Simulation and Flight
  - Waypoint navigation, control methodology, obstacle avoidance
- Two Challenges earn Points, highest point earner wins
- Top 6 teams will advanced to Hardware Kit Build and Top 3 for Flight Exhibition

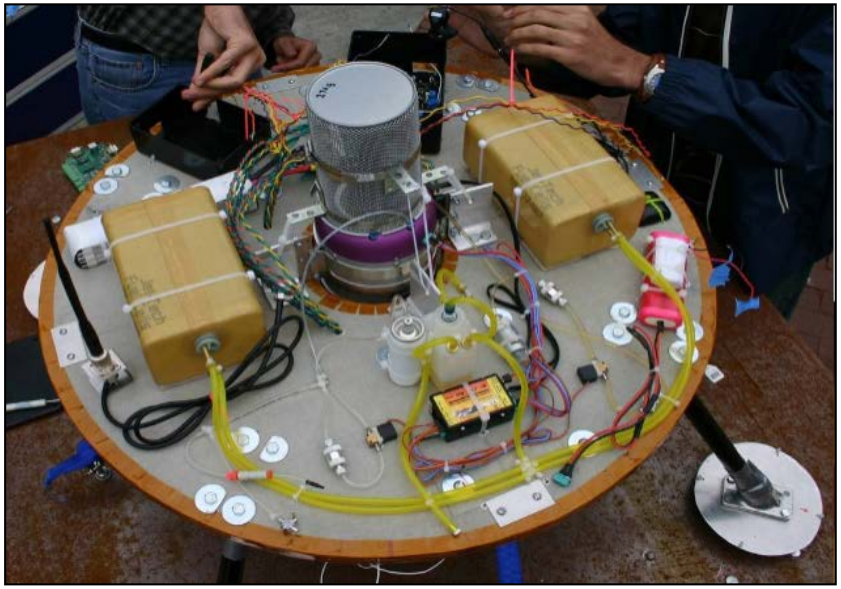
## Kit Boot Camp and Flight Exhibition

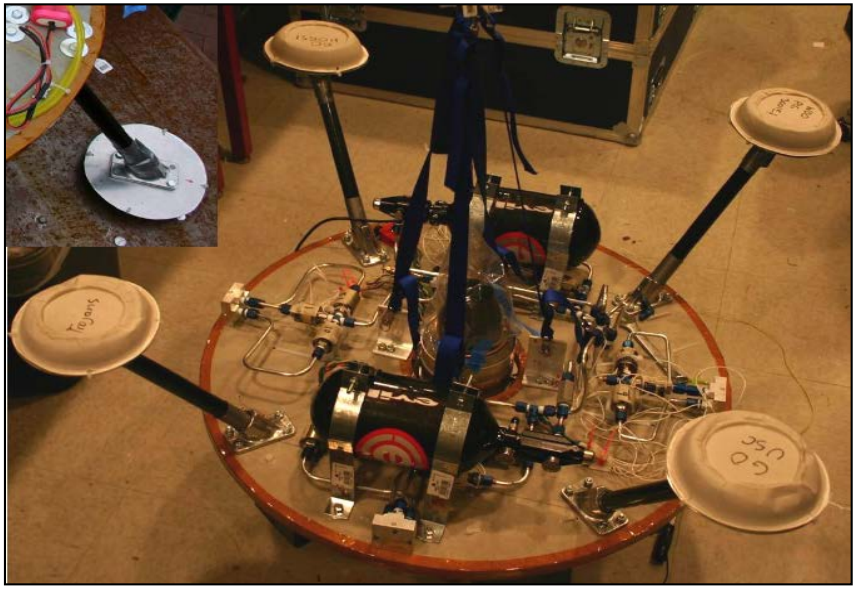
**Goal:** Enable teams from S/W challenge to build full kit (without Engine), and run Exhibition Flights with Winning S/W

- Teams from S/W Challenge (first 6 at minimum) will receive full hardware "Kit"
- Boot Camp will be run during summer to help all teams "Build" their Lunar Lander Vehicle
- Exhibition Flights will be run in CA for the Top three Teams in the S/W challenge

# What is LEAPFROG?

**LEAPFROG** (**Lunar Entry and Approach Platform For Research On Ground**) was started as a multi-semester design-to-flight student hands-on training activity through Astronautical Engineering and Information Sciences Institute at the University of Southern California in **2006**.

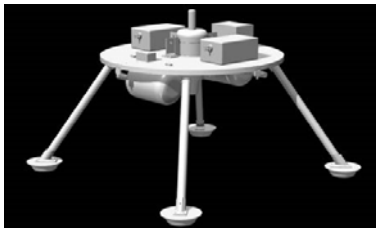




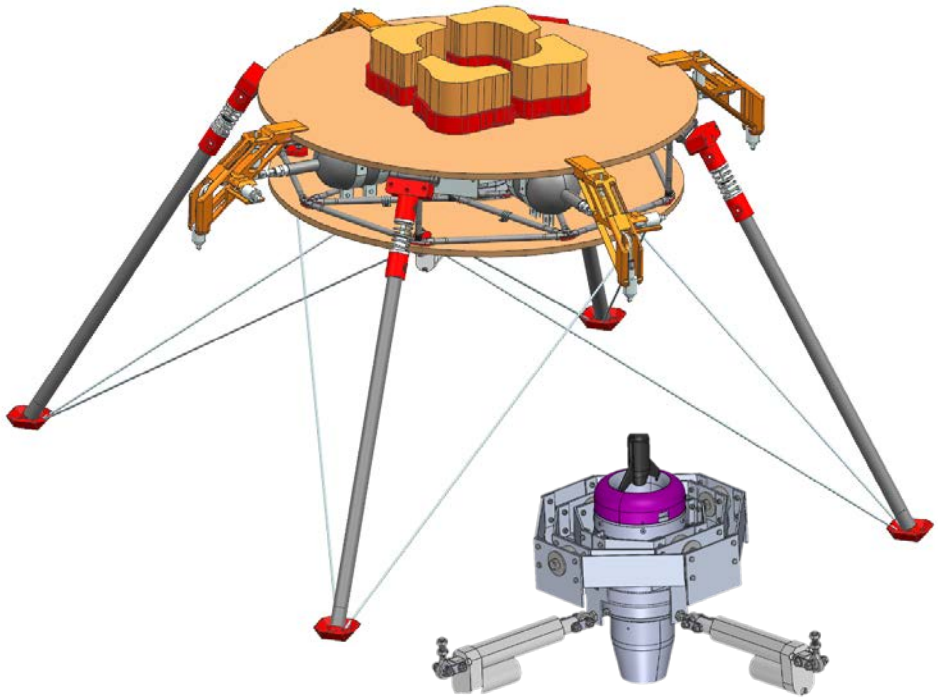
LEAPFROG

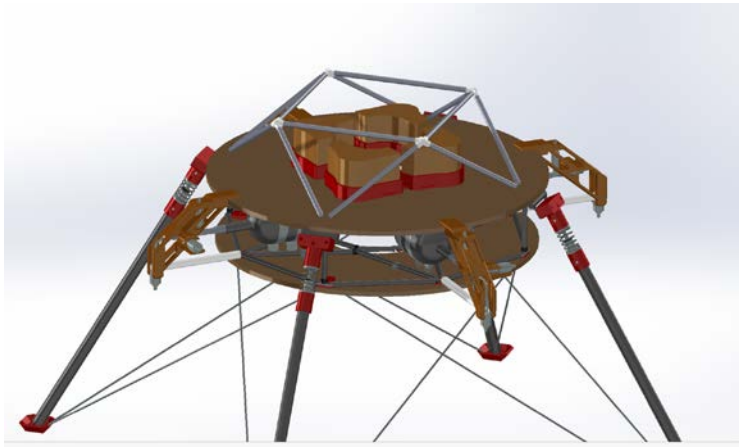
# LEAPFROG taught Lander Systems Engineering through Hands-On Flight Test

***LEAPFROG Generational Vehicles designed to fly multiple times in single day***



# Artemis LEAPFROG Challenge Vehicle has been modified for Safety and Ease of Ops

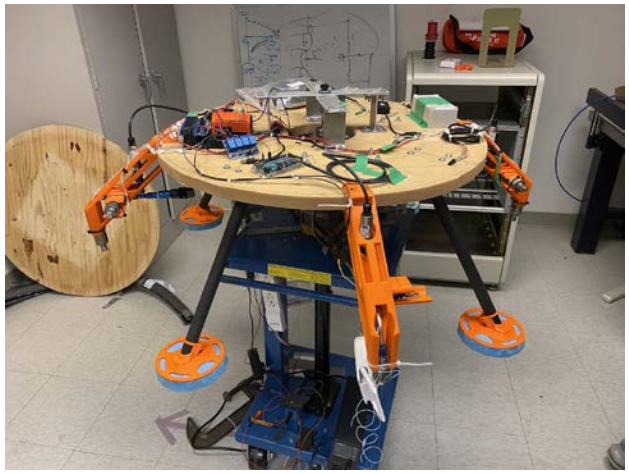




**Gen-2 LEAPFROG System Features:**

- Gimbaled JetCat P300 Jet Engine for translation
- Cold gas ACS w/4 independent paintball bottles, fillable anywhere
- Carbon fiber chassis built with mechanical fuses and spring joints for hard landing and failsafe landing structure
  - "Roll cage" on top and bottom
  - Designed to land on Slopes
- Onboard GNC Avionics w/ GPS fence
- Two low Cost foam core fiberglass platforms, lightweight and strong, replaced easily, more surface area for mounting
- 4 separate small Kerosene tanks incorporated onto centerpoint, minimizes slosh, spreads CG

# Flight Vehicle Test Platforms in use to validate safe operations



Air Bearing Platform for ACS Testing

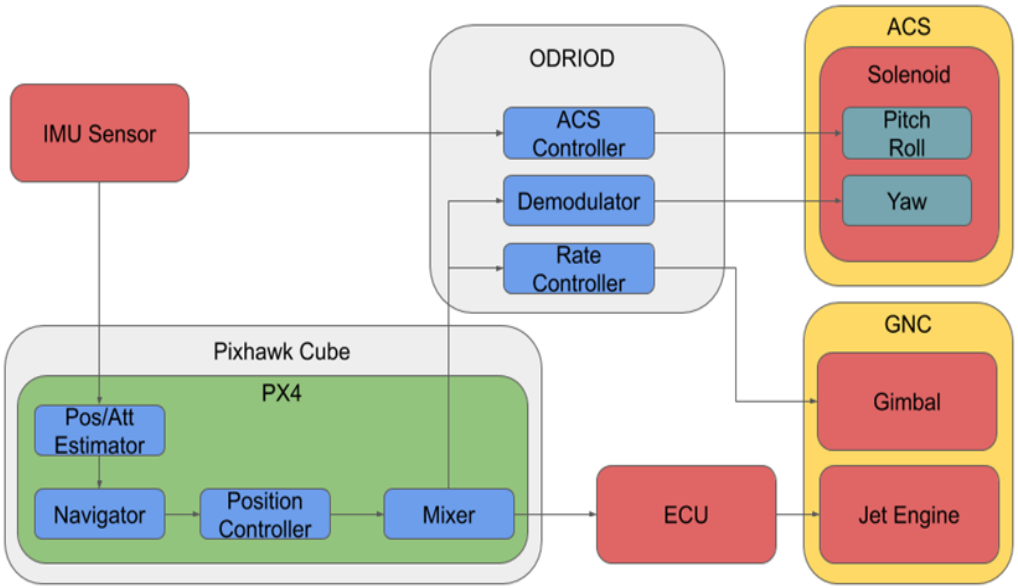
*Full Scale*

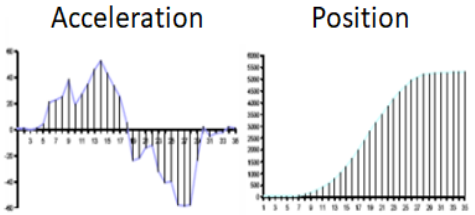
TVC Test Platform for Gimbal Testing

Static Test Stand for Integration, and Hold-Down Engine Testing

# Software Competition exercises Lunar Lander based Guidance, Navigation and Control

- LEAPFROG Gimbal control is tied into a COTS Flight controller, **PixHawk**
  - Open source software PX4 on low cost controller, able to be used by all University teams across country
  - The “code” challenge will test programming in control methods for relative positioning, altitude control, waypoint navigation, with sensor limits on velocity and angle



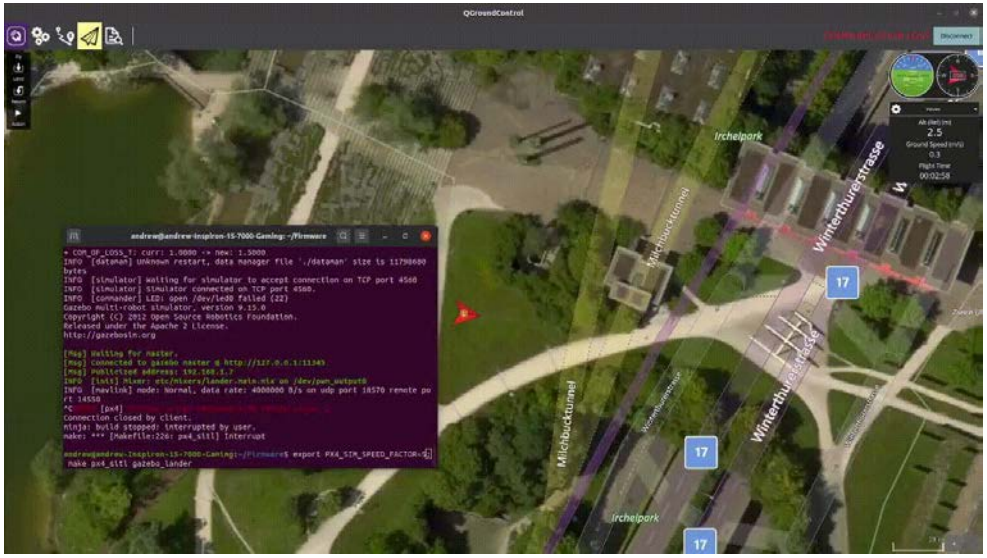




Position Estimation Algorithm Graph
(diagrams from paper on IMU sensor)

Image provided by PX4 documentation

# Software Challenge uses PixHawk Simulation Software

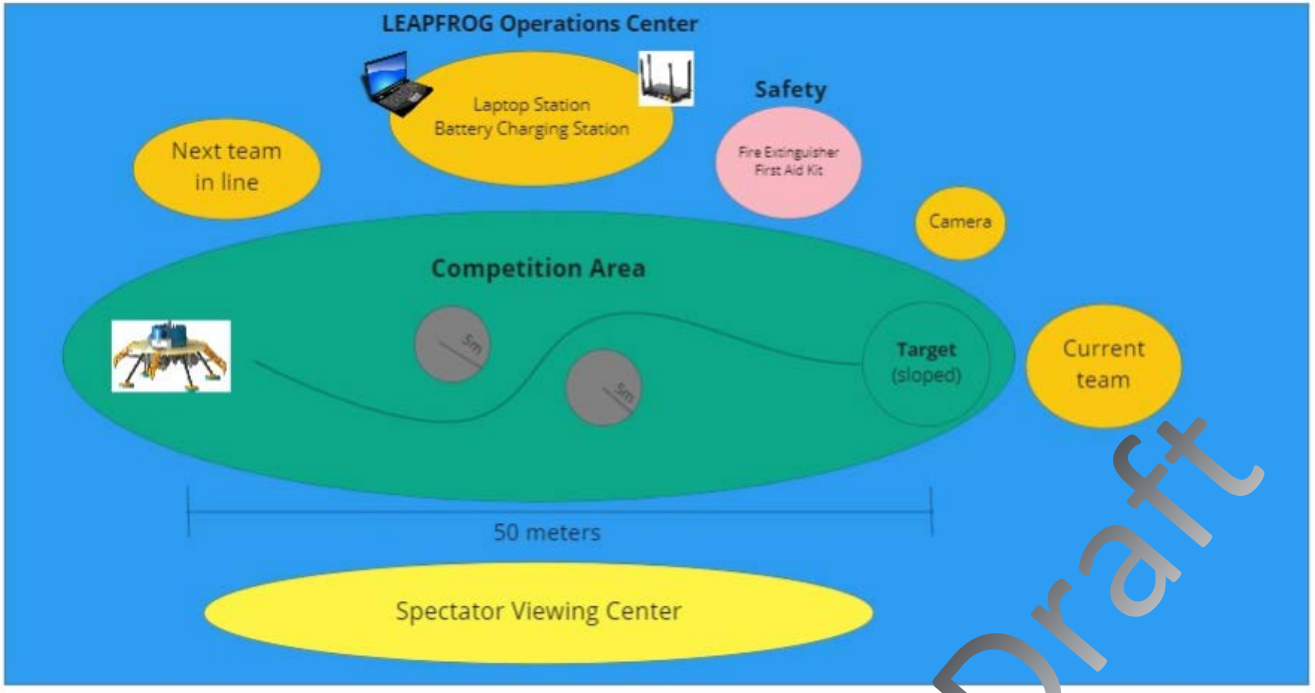
- Basic simulation with plant model of LEAPFROG components created
- Generic Earth centric physics model applied, uses Gazebo for visualization
- PixHawk controller algorithms integrated with open source tools into simulation
- Scenario provided to mimic dimensions and geography of competition RC Field




- *The bridge between the Software and Flight Challenge is the PIXHAWK CONTROLLER*

# Initial Flight Challenge Scenario:
## Presented in Seminar #2

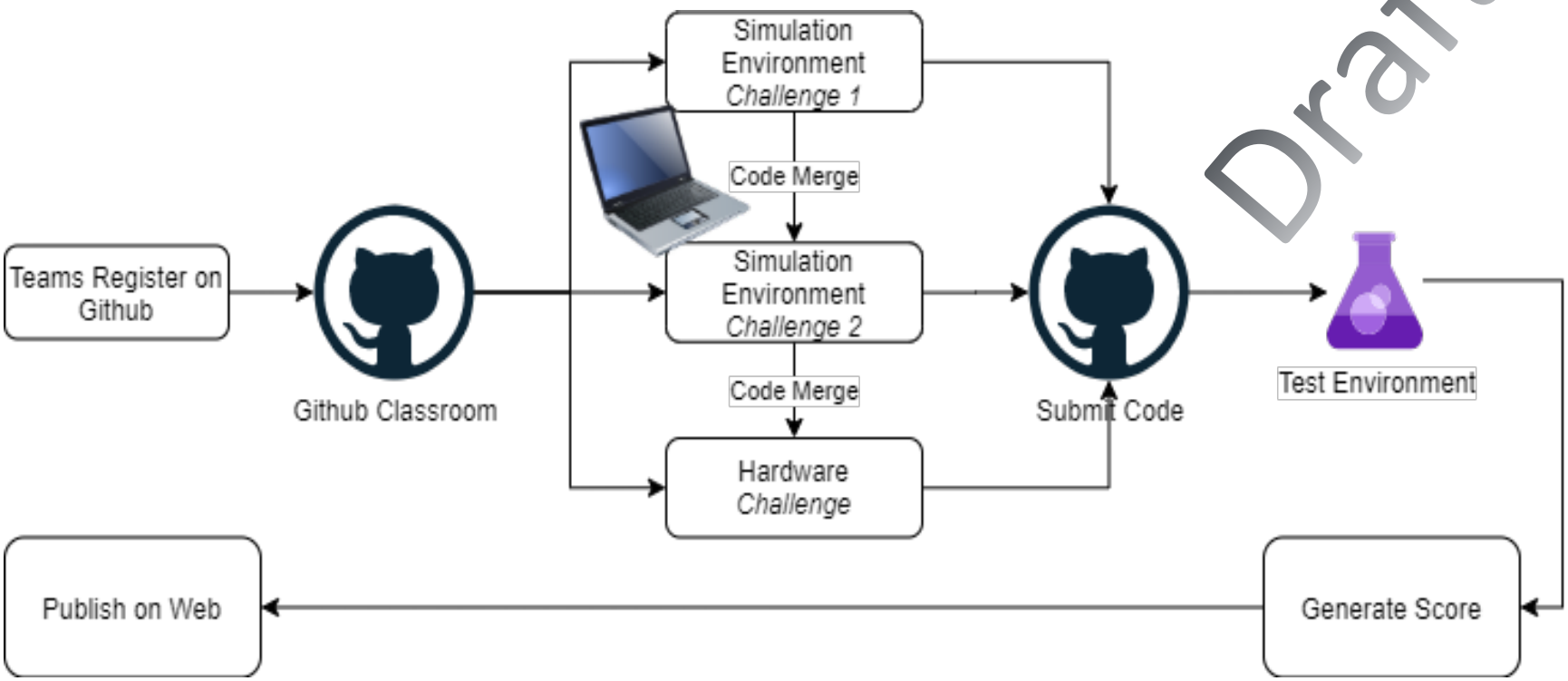
- Flights proposed at RC Fields around US
- One LEAPFROG Vehicle per Field, Each Team flies multiple times
- “Craters” are markings on Field, “obstacles” are pre-programmed into flight controller
- Flight Competition Metrics under development:
  - Flight Time
  - Stability of Flight
  - Navigation and Landing Precision
  - Fuel Usage
  - TBD




- *Payload Delivery is considered an Option at this point*

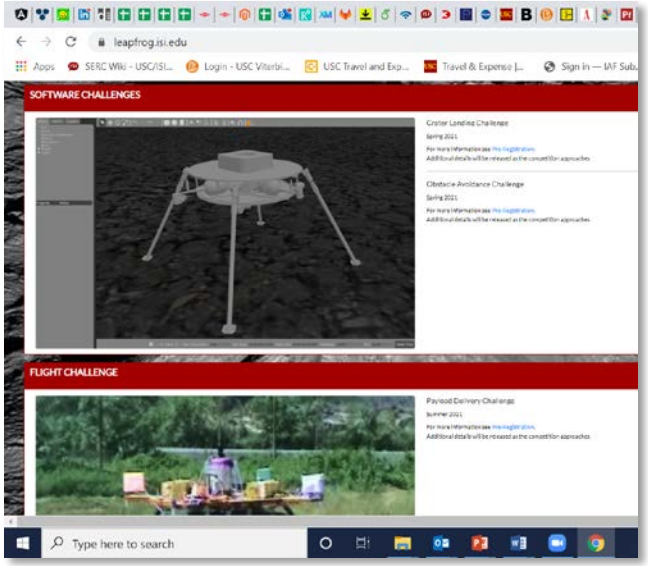
# Initial Plan for Teams to share Simulation and Flight Code

## (Presented in Seminar #2 and #3)



# Where to get more Information?

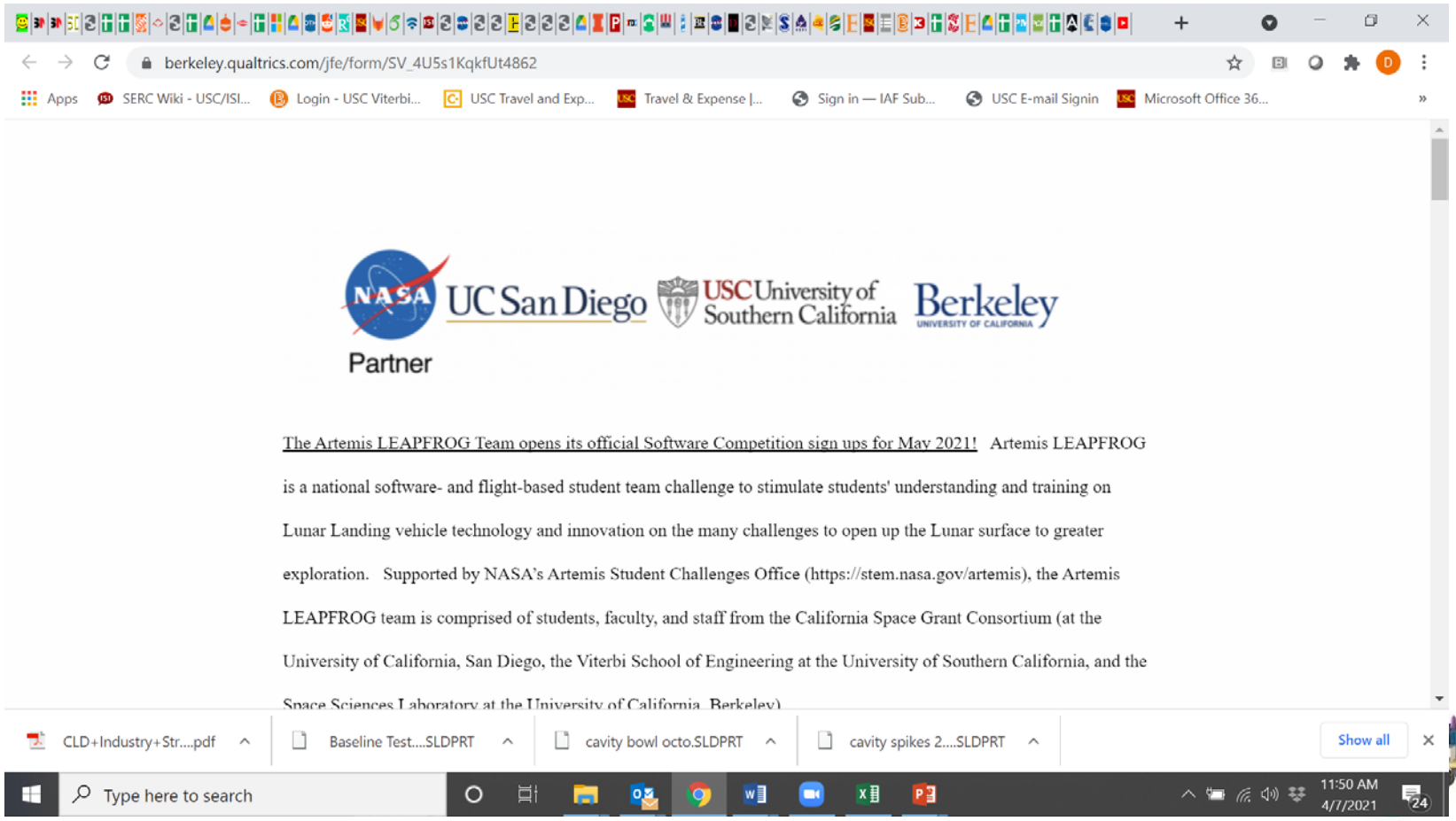
- **“LEAPFROG.ISI.EDU”**


- **Competition Information will be provided**
- **Vehicle build updates**
- **Link to the Registration**
- **Links to NASA Artemis STEM Project Information**
- **Information about the LEAPFROG Team members**

# Registration Page is LIVE!

- Dedicated Survey Link located on leapfrog.isi.edu web page
  - ***https://berkeley.qualtrics.com/jfe/form/SV_4U5s1KqkfUt4862***
- Qualtrics will be used to upload competition teams software and applications, scoring and team progress



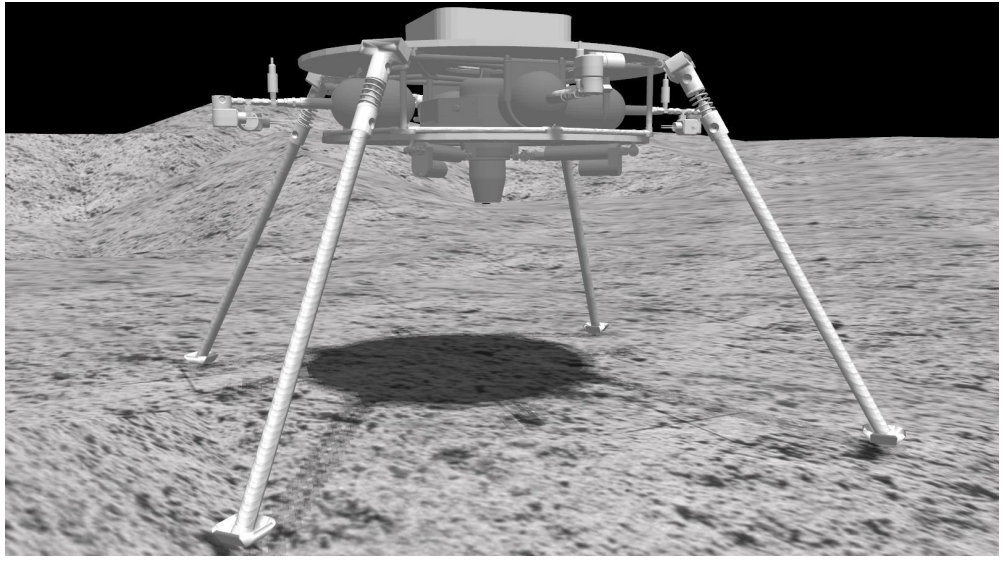
# Whom to Contact

- **Fill out Survey on Website (leapfrog.isi.edu)**
- **Information E-mail: leapfrog@usc.edu**
- Technical and Competition Contact:
  - Prof David Barnhart, Barnhart@isi.edu
- Programmatic Contact:
  - Prof John Kosmatka, jkosmatka@ucsd.edu

# DETAILS FOR SOFTWARE TOOLSETS

# LEAPFROG Webinar 1: Simulation Overview

April 7, 2021

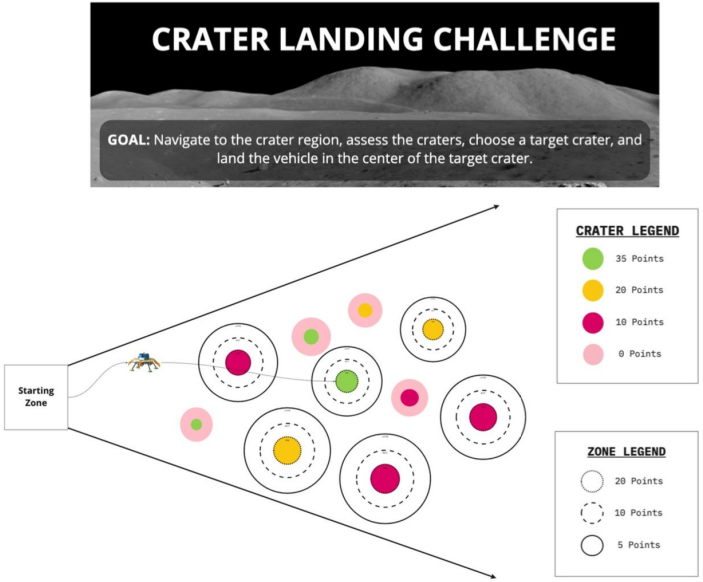


# Outline

1. **Software Challenge Overview**
2. **Vehicle Systems**
3. **Simulation Tools**
4. **Simulation Overview**
5. **Summary**

# Software Challenge Overview

1.) Create the controllers necessary to stabilize the vehicle in simulation
2.) Develop navigation systems to complete the Crater Landing Challenge
   a.) Optimize time
   b.) Fuel usage
   c.) Crater target score

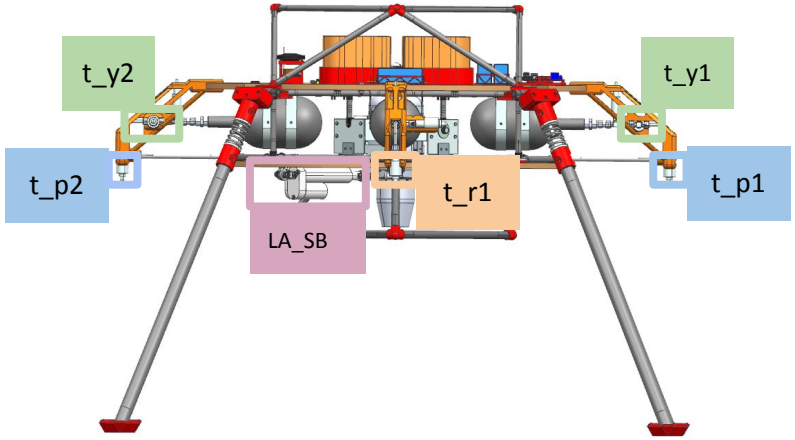


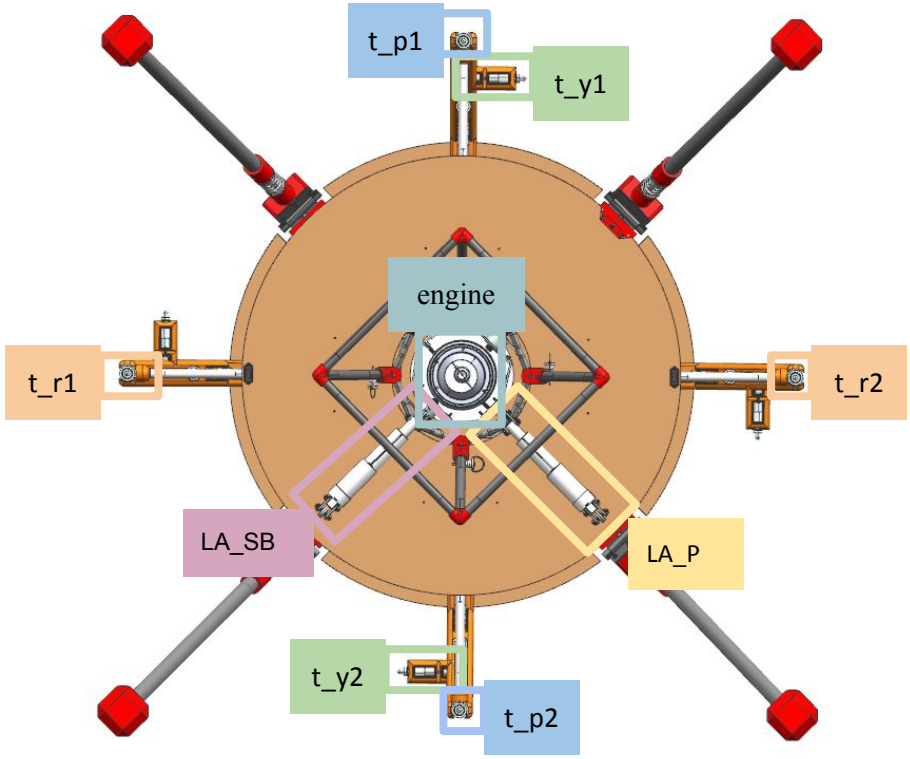

**OVERVIEW:** This challenge will test teams' ability to navigate and control the LEAPFROG vehicle as well as their ability to assess a lunar landscape.

# Vehicle Systems

**Thrusters (2.5N):**
t_p1/2 : pitch thrusters
t_r1/2 : roll thrusters
t_y1/2 : yaw thrusters

**Linear Actuators (900N):**
LA_S : starboard actuator
LA_P : port actuator
**Engine (300N)**

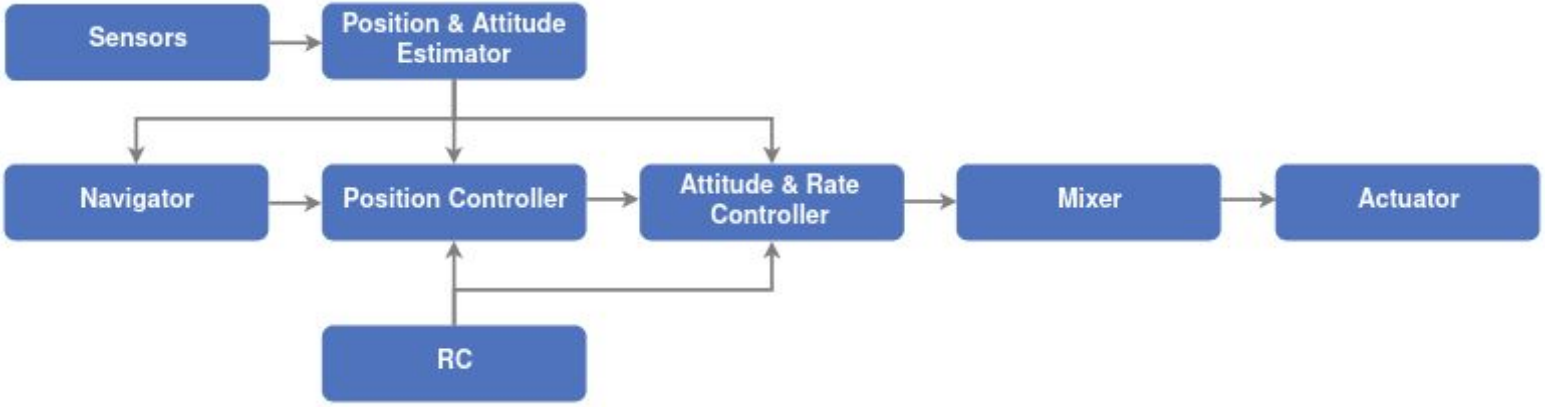


# Simulation Tools: PX4

What is PX4?

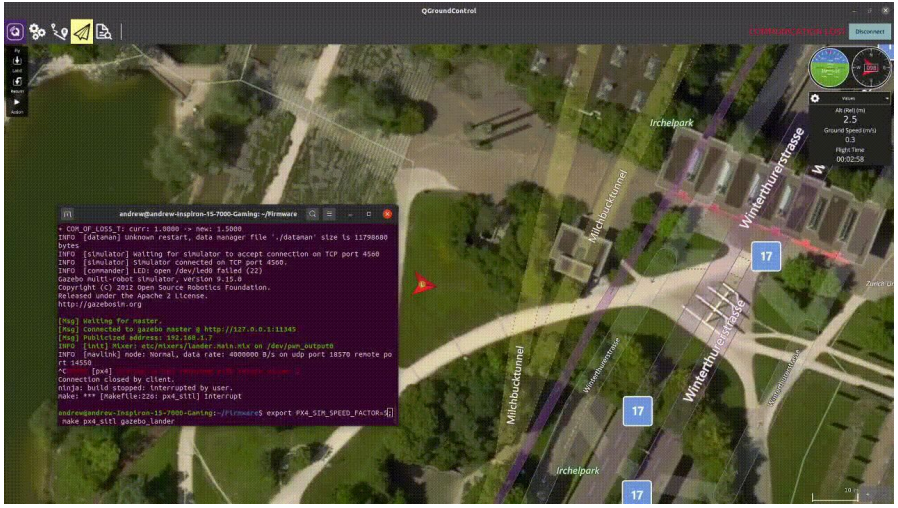
- Open source flight control software that is often used in drones and other unmanned vehicles
- Has been extended to include support for LEAPFROG system.



# Simulation Tools: Software in the loop (SITL)

What is a SITL?

- Flight stack runs on computer in a way that simulates dynamics and controls of real vehicle
- Consists of variant of PX4 that is integrated with simulation environments



# Simulation Tools: MAVLink

What is MAVLink?

- Lightweight communication protocol used for air vehicles
- Provides set of standardized messages for telemetry, vehicle status, and commands
  - We have extended the standard messages with custom messages to aid in tuning of controllers
- Implemented in C, C++, Python, and more
  - Provides standard way to generate bindings for any language

# Simulation Tools: Gazebo

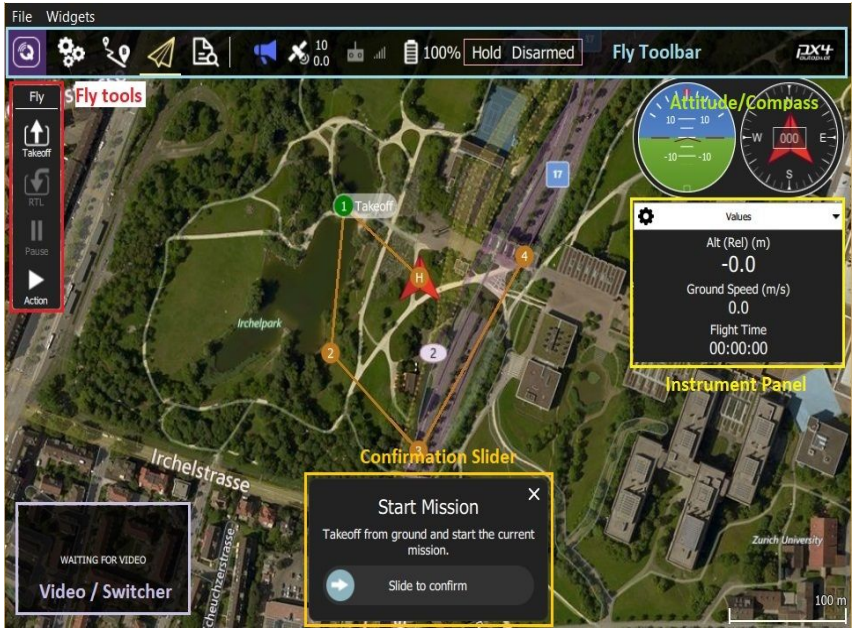
What is Gazebo?

- Simulation environment with robust physics engines with versatility and support for developing plugins
- Create custom worlds
- Competition environment and scoring added

GAZEBO

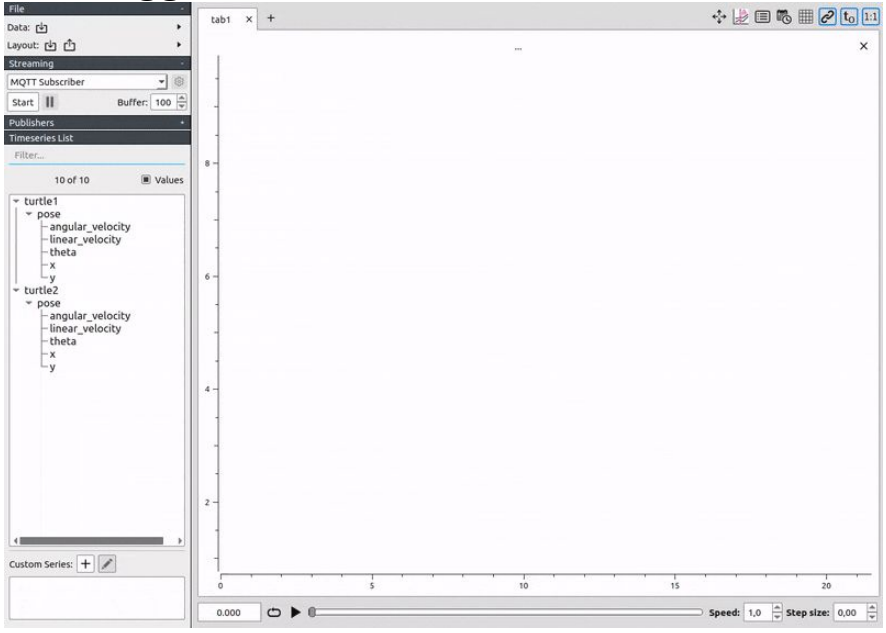
# Simulation Tools: Visualization tools

## QGroundControl




https://docs.qgroundcontrol.com/master/en/FlyView/FlyView.html

## PlotJuggler




https://github.com/facontidavide/PlotJuggler

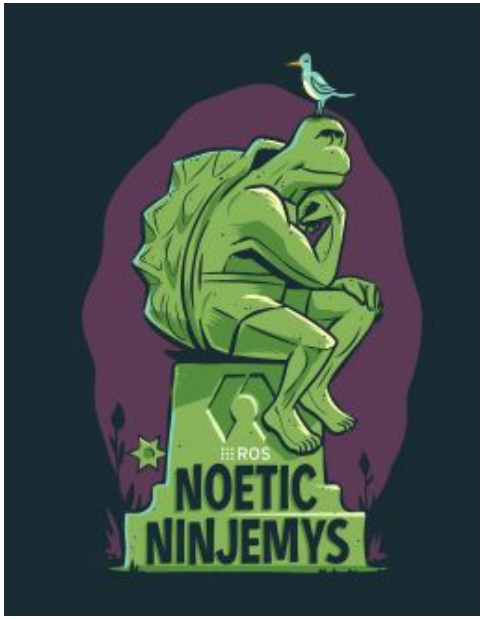
# Simulation Tools: ROS/MAVROS

What is ROS?

- Robot Operating System (ROS) is framework for writing and using robotics software
- Contains collection of tools, libraries and networks that simplify creation of complex robots on custom platforms
- Utilizes Pub-Sub system for easy communication across any ROS compatible nodes

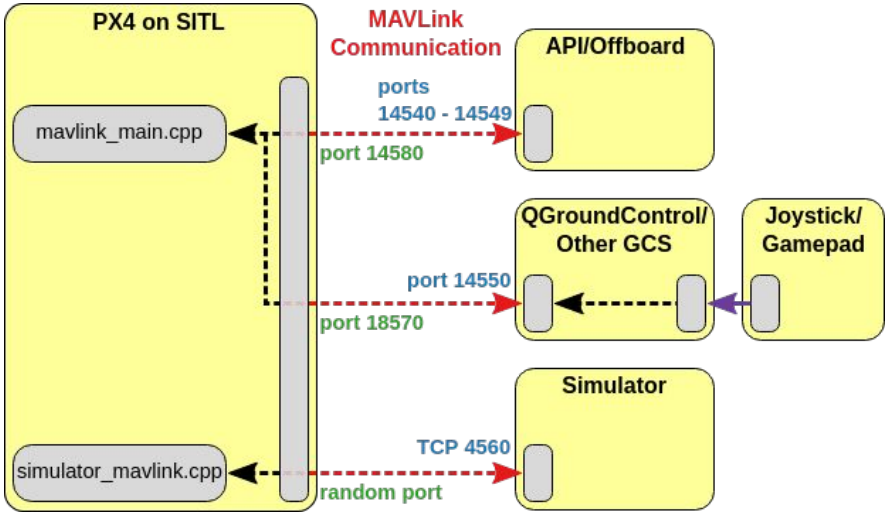
What is MAVROS?

- MAVLink extendable communication node for ROS that easily connects directly to PX4 and connects the communication system that PX4 uses to that of ROS



# Simulation Overview: How does it actually work?

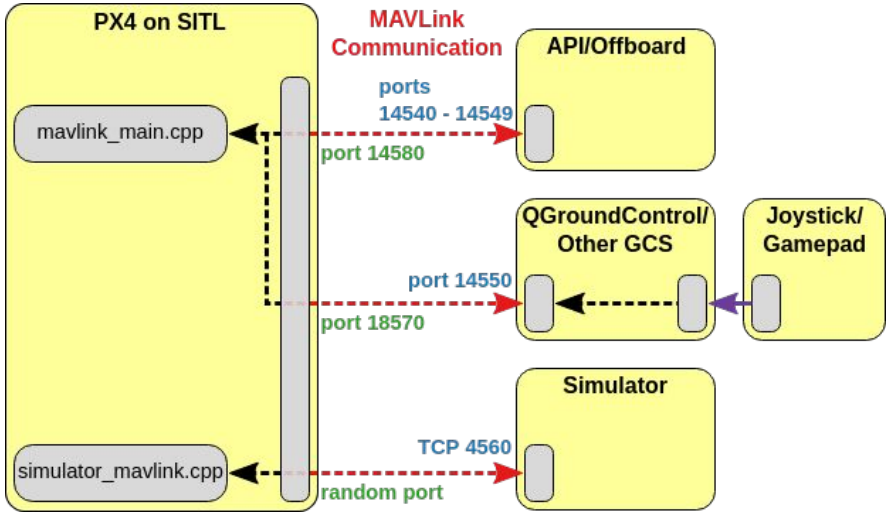
1.) PX4 on SITL mode
2.) Simulator (Gazebo)
3.) QGroundControl
4.) Offboard Controls




https://docs.px4.io/master/en/simulation/#sitl-simulation-environment

# Simulation Overview: How does it actually work?

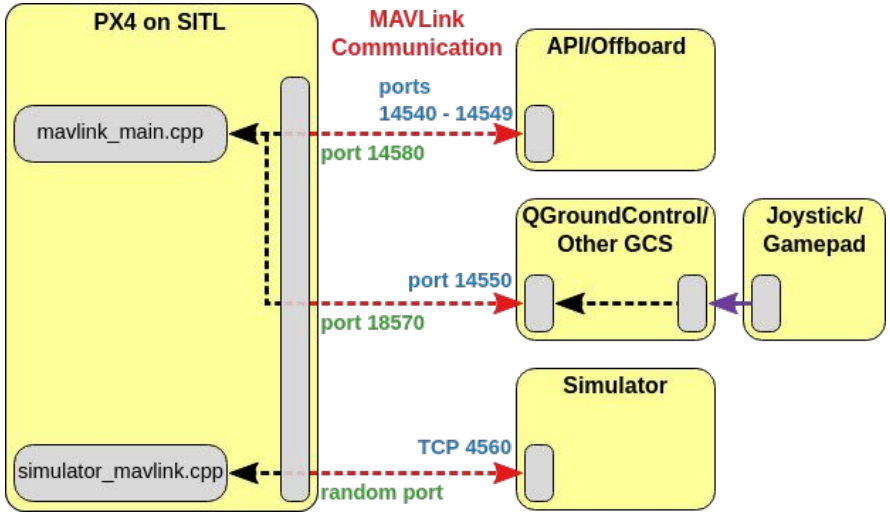
1.) PX4 on SITL mode
   a.) Disconnects main controllers and hardware tests and substitutes with SITL version
   b.) Interacts with all external applications using MAVLink
2.) Simulator (Gazebo)
3.) QGroundControl
4.) Offboard Controls




https://docs.px4.io/master/en/simulation/#sitl-simulation-environment

# Simulation Overview: How does it actually work?

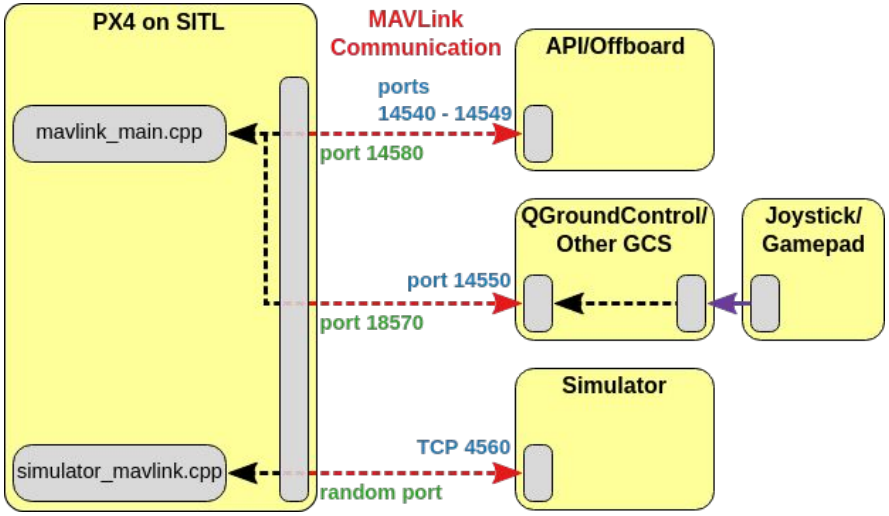
1.) PX4 on SITL mode
2.) Simulator (Gazebo)
    a.) Contains custom plugins for necessary controllers (ACS and TVC)
    b.) Sensor plugins (IMU, groundtruth, magnetometer, etc.)
3.) QGroundControl
4.) Offboard Control




https://docs.px4.io/master/en/simulation/#sitl-simulation-environment

# Simulation Overview: How does it actually work?

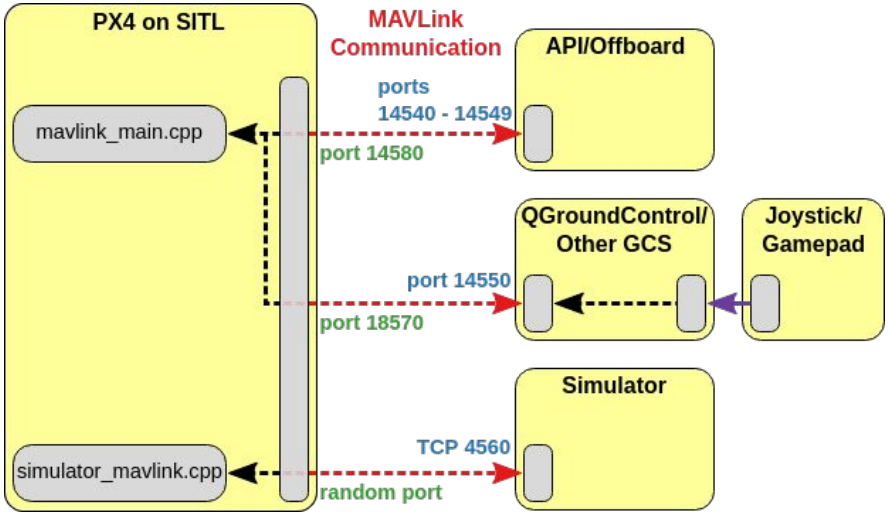
1.) PX4 on SITL mode
2.) Simulator (Gazebo)
3.) QGroundControl
    a.) Connects to PX4 via MAVLink to provide GUI for control of vehicle
4.) Offboard Control




https://docs.px4.io/master/en/simulation/#sitl-simulation-environment

# Simulation Overview: How does it actually work?

1.) PX4 on SITL mode
2.) Simulator (Gazebo)
3.) QGroundControl
4.) Offboard Control
    a.) MAVLink communication allows for easy extensibility and control of vehicle
    b.) Recommended way of creating custom offboard system is to use ROS/MAVROS




https://docs.px4.io/master/en/simulation/#sitl-simulation-environment

# Summary

Today, we...

- Broke down LEAPFROG vehicle's layout and systems
- Went over PX4, SITL, MAVLink, Gazebo, ROS/MAVROS, QGroundControl, and PlotJuggler
- Identified major components and links pertaining simulation